Criteria for It-from-Bit Compatibility: A Taxonomy of Information-Origin Attributes in Physics and Biology

Douglas C. Youvan

doug@youvan.com

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What if the fabric of reality is not made of matter or energy, but of information? John Archibald Wheeler's bold proposition—*"It from Bit"*—suggests that all physical phenomena arise from fundamental binary decisions. But how do we test such a claim? This paper offers a rigorous framework to evaluate whether specific physical and biological attributes are genuinely rooted in information-theoretic primitives. We define five foundational criteria—ranging from binarity and asymmetry to scale persistence and informational amplification—and apply them across quantum mechanics, molecular biology, cosmology, and classical physics. Through a comparative taxonomy and scoring analysis, we identify which features of the universe most likely originate from bits and which are better understood as emergent or statistical. The results suggest that quantum measurement, entanglement, and biological homochirality may reflect deep informational structures, while classical properties like temperature or mass do not. The paper concludes with a reflection on Wheeler's vision and its implications for physics, the origin of life, and AI. If some things are not merely described by bits but truly made of them, then the nature of existence must be rethought—from the bottom up.

Keywords: It from Bit, information ontology, Wheeler, quantum measurement, chirality, emergence, symmetry breaking, homochirality, genetic code, quantum foundations, ontology, physics of information, binary structure, quantum biology, epistemology, foundational physics. A collaboration with GPT-4o. CC4.0.

Abstract

This paper introduces a principled framework for determining whether a given physical or biological attribute can be meaningfully traced to a fundamental informational origin, in line with John Archibald Wheeler's influential "It from Bit" hypothesis. According to this view, every entity, event, or structure in the universe ultimately derives from discrete binary decisions—yes/no outcomes at the most foundational level of reality. To operationalize this idea, we identify a set of *foundational criteria* (such as binarity, asymmetry, scale persistence, and measurement involvement) and *secondary heuristics* (including classical intractability and cross-domain recurrence) to evaluate the degree to which various phenomena conform to an informational genesis.

Using these criteria, we classify and compare a wide range of attributes—ranging from quantum spin, charge, and entanglement, to molecular chirality, genetic code structure, and cosmological asymmetries such as matter-antimatter imbalance and the arrow of time. This taxonomy enables clearer distinctions between properties that are likely rooted in binary informational distinctions and those better understood through classical or emergent field-based explanations. The implications of this distinction are far-reaching: if certain asymmetries and constants of nature originate from primordial information events, then our physical theories may require reformulation not around continuous variables but around conserved informational choices. We conclude by outlining theoretical and experimental paths forward to test the ontological status of information in physics, biology, and the origin of life.

1. Introduction

1.1 The "It from Bit" Hypothesis

John Archibald Wheeler's provocative proposal—that every physical "thing" (the *It*) ultimately emerges from binary informational choices (the *Bit*)—marks a radical shift in the foundations of physics. Rather than assuming that particles, fields, or spacetime themselves are fundamental, Wheeler suggested that information—the

most basic binary distinction between “yes” and “no,” “0” and “1”—is the underlying substrate of reality. In this view, the universe is not merely described by information; it is *made* of information.

The consequences of this view are profound. If physical laws, particles, and emergent structures such as molecules, cells, or even consciousness arise from discrete informational events, then our ontology must invert: material phenomena are not the basis of reality, but rather the downstream effects of decisions made at the informational level. This aligns with other developments in theoretical physics, including quantum computation, black hole entropy, and the holographic principle, all of which hint at a deep connection between information and physical law. However, these remain largely metaphorical without a robust methodology for testing which attributes of the physical world are genuinely “It-from-Bit” compatible.

1.2 The Need for a Discriminatory Framework

While Wheeler's slogan is conceptually powerful, it lacks formal boundaries. Not all physical phenomena are easily described in terms of bits, nor is it clear which phenomena *should* be. Without rigorous criteria, the "It from Bit" hypothesis risks becoming an aesthetic metaphor rather than a scientific tool. We therefore face a critical need for a discriminatory framework—a set of necessary and sufficient conditions to assess whether a given property plausibly originates from a binary informational substrate.

This is not merely a philosophical exercise. The distinction between information-rooted and emergent properties has implications for quantum gravity, the origin of life, symmetry breaking, and the interpretability of AI systems. Moreover, it raises the possibility that certain asymmetries observed in the universe—such as chirality, charge, or the arrow of time—may not be emergent from higher-order field equations, but instead *encoded* from the outset as informational priors. To test this idea, we must first ask: what features signal an informational origin?

1.3 Overview of Approach and Goals

This paper proposes a structured method for evaluating *It-from-Bit compatibility* across a diverse set of physical and biological attributes. We begin by defining a set of foundational criteria—including binarity, irreducible asymmetry, scale stability, participation in measurement, and information conservation—that serve as primary indicators of informational origin. We then identify secondary heuristics such as resistance to classical modeling, recurrence across domains, and what we call the *Bit Induction Test*—whether a property can, in principle, be modeled as arising from a series of binary distinctions.

Using this framework, we construct a comparative taxonomy of attributes from three major domains: quantum physics, molecular biology, and cosmology. These include well-studied candidates such as spin and entanglement, more speculative examples such as biological homochirality, and ambiguous cases like mass or temperature. By scoring each attribute across the criteria, we aim to distinguish between those likely rooted in information and those better treated as emergent properties of continuous fields or statistical processes.

Ultimately, the paper seeks to clarify the ontological boundaries of Wheeler's insight. Which aspects of the universe are truly informational in origin, and which merely *appear* so due to our modeling preferences? By answering this, we open the door to reformulating not only physics, but also biology, computation, and metaphysics, along fundamentally informational lines.

2. Foundational Criteria for Compatibility

To evaluate whether a given physical or biological attribute can plausibly be said to emerge from an underlying binary informational substrate—i.e., to be *It-from-Bit*-compatible—we must articulate a set of stringent, testable criteria. These criteria form the core of our analytical framework and are meant to distinguish between attributes that are merely described by information and those that are ontologically informational in origin.

Each criterion below represents a necessary (though not always sufficient) condition. Attributes that meet most or all of these foundational criteria are strong candidates for having their origin in fundamental informational distinctions.

2.1 Discreteness and Binary Structure

The most direct indicator of informational origin is the presence of discrete, ideally binary, state structures. A system or attribute that resolves into countable alternatives—particularly dichotomous ones—is inherently suited to being described in terms of bits. Binary distinctions are the core units of information; without discreteness, the notion of a bit becomes meaningless.

Examples:

- Quantum spin: Spin-½ particles exist in quantized up/down states.
- Electric charge: Exists in discrete multiples of fundamental units.
- Genetic codons: Consist of discrete nucleotide triplets (digital encoding).

Implication: If an attribute cannot, even in principle, be reduced to discrete choices, then it is unlikely to originate from bit-based processes. Continuous or analog structures (like temperature or pressure) may be modeled informationally, but they do not embody the ontological discreteness of bits.

2.2 Irreducible Asymmetry

An attribute is more likely to stem from information if it embodies a directional or unbalanced distinction that cannot be undone without loss. Binary information introduces a difference: 0 is not 1. Thus, physical or biological properties that reflect broken symmetries or persistent asymmetries are suggestive of informational origins.

Examples:

- Molecular chirality: Left-handed amino acids dominate life, despite symmetric physical laws.
- CP violation: The matter–antimatter imbalance implies an early Universe asymmetry.
- Time’s arrow: Entropy increases irreversibly.

Implication: Symmetry breaking can be understood as a “choice” at the informational level. Irreducible asymmetry implies that a binary decision was locked in and preserved through physical instantiation.

2.3 Scale Stability and Persistence

For an informational origin to be meaningful, the attribute in question must persist across multiple levels of scale, from the quantum to the macroscopic. This ensures that the bit-based decision was not ephemeral or local, but capable of scaffolding higher-order structures.

Examples:

- Electron spin: Impacts chemical bonding, which underlies macroscopic material properties.
- Homochirality: Reproduced reliably in biological replication across generations.
- Genetic information: Scales from base-pair encoding to organismal function.

Implication: If the attribute dissolves or loses coherence as it scales, it likely arises from thermodynamic emergence rather than informational determination. True "It-from-Bit" attributes should be architecturally foundational.

2.4 Involvement in Measurement or State Collapse

According to Wheeler's participatory universe hypothesis, reality does not exist in definite form until *observed*—a notion echoing the role of measurement in quantum mechanics. Attributes that emerge only upon observation or interaction suggest a deeper entanglement with information.

Examples:

- Quantum state collapse: A bit is effectively "written" at the moment of measurement.
- Wavefunction outcomes: Spin, polarization, and location are not determined until interaction.

Implication: If a property arises or stabilizes through measurement-like processes, then it is not merely informationally *describable*—it is informationally *generated*. This is a key marker of ontological bit-instantiation.

2.5 Information Conservation or Amplification

Attributes with an informational origin should participate in conservation laws for information or contribute to its amplification over time. They should either preserve bit-distinctions without loss, or recursively use them to generate higher-order patterns or codes.

Examples:

- Genetic code: Not only preserves but also amplifies information via replication and expression.
- Topological invariants: Retain encoded structure despite physical deformation.
- Entanglement: Distributes information nonlocally while preserving correlations.

Implication: Information that gets erased, scrambled, or washed out in physical processes may be incidental, not foundational. Conversely, if an attribute *generates* more distinguishable information, it acts as a causal node in the universe's informational architecture.

Synthesis

Taken together, these criteria establish a high bar for "It-from-Bit" compatibility. The most compelling candidates will:

- Encode binary distinctions at the base level,
- Reflect irreversible symmetry breaking,
- Persist across scales of organization,
- Depend on or crystallize through measurement,
- And act as stable carriers or amplifiers of informational content.

In the next section, we introduce secondary heuristics—less fundamental but still useful tests—for evaluating ambiguous or edge-case phenomena.

3. Secondary Heuristics

While the foundational criteria offer necessary conditions for determining whether an attribute may originate from binary informational primitives, they are not always sufficient to fully capture ambiguous or borderline phenomena. Some physical and biological features partially satisfy the primary criteria, or manifest at levels not easily reducible to experimental confirmation. For these cases, we introduce secondary heuristics—less rigorous but still illuminating lenses that help refine the classification of *It-from-Bit* compatibility.

These heuristics serve as guiding principles or "soft indicators" that can assist in evaluating difficult cases. While not definitive on their own, they often reveal

whether an attribute aligns with the spirit of Wheeler's hypothesis, especially when foundational criteria yield inconclusive results.

3.1 Resistance to Classical Explanation

Definition: An attribute is more likely to be *It-from-Bit* compatible if it cannot be fully or elegantly explained within classical, continuous, or deterministic frameworks.

This heuristic rests on a negative test: when classical physics fails to account for the structure, behavior, or origin of a property, we are justified in turning to information-theoretic explanations. Attributes that demand quantum, topological, or computational models suggest a departure from analog fields and a shift toward discrete informational events.

Examples:

- Quantum entanglement: Defies classical locality and causal closure.
- Chirality bias in biochemistry: Not readily derivable from thermodynamic equilibrium models.
- CP violation: Anomalous within classical symmetries of particle physics.

Implication: Resistance to classical modeling hints that an attribute may not emerge from continuous physical law alone, but from a deeper layer of binary informational structure. While this does not prove informational origin, it indicates a domain where *It-from-Bit* models may offer more explanatory power.

3.2 Cross-Domain Universality

Definition: An attribute is more likely to have an informational origin if it recurs across multiple domains (e.g., physics, chemistry, biology) in structurally or functionally analogous ways.

This heuristic is based on a principle of informational resonance: if a pattern, asymmetry, or structure appears in unrelated systems and scales, it may stem from a shared informational substrate. The repetition of certain binary-encoded distinctions in different contexts suggests that the bit is not just a local artifact, but a generative principle.

Examples:

- Chirality: Appears in particle physics (neutrino handedness), organic chemistry (molecules), and biology (L-amino acids).
- Digital codes: DNA, computer systems, and neural encoding all use symbolic alphabets reducible to binary form.
- Spin quantization: Impacts atomic structure, magnetism, and quantum computing.

Implication: Cross-domain recurrence implies that the attribute is not emergent from isolated system conditions but reflects a global bias embedded in the structure of reality itself—a mark of bit-level architecture.

3.3 Minimal Encodability (Bit Induction Test)

Definition: An attribute is more likely to be *It-from-Bit* compatible if it can, in principle, be reconstructed or instantiated from a series of binary choices—even if those choices are probabilistic or contextual.

This is perhaps the most constructive heuristic, a positive test for *bit generativity*. The idea is simple: if a property can be built from or reduced to a minimal sequence of binary distinctions (e.g., decisions, measurements, rule applications), then it may be said to arise from bit-level architecture.

Examples:

- Spin states: Clearly modeled by qubits.
- Genetic codons: Derivable from four-base systems (2 bits per base pair).

- Topological structures: Invariant classes reducible to binary classifications (e.g., even/odd winding numbers).

Implication: The *Bit Induction Test* acts as a philosophical razor: it slices away emergent complexity to ask whether the attribute *could* exist in a universe made entirely of bit-wise operations. If the answer is yes, the attribute may be informationally primitive.

Synthesis of Heuristics

These three heuristics help refine our framework by:

- Pointing us toward attributes that classical physics cannot account for;
- Highlighting informational motifs repeated across physical and biological domains;
- Offering a constructive test for whether something *can be built from bits*.

When an attribute satisfies both foundational criteria and one or more of these heuristics, its case for *It-from-Bit* compatibility becomes compelling. In the next section, we apply this framework to a taxonomy of specific attributes drawn from quantum physics, biology, and cosmology.

4. A Taxonomy of Attributes

Having established a framework for evaluating *It-from-Bit* compatibility through foundational criteria and secondary heuristics, we now apply this framework to a curated taxonomy of physical and biological attributes. These attributes have been grouped into four categories based on their domain of origin and compatibility strength. This section will assess how well each attribute aligns with the notion of originating from binary informational primitives.

4.1 Quantum Attributes

Quantum phenomena are the most promising candidates for *It-from-Bit* origins, as quantum mechanics is inherently probabilistic, discretized, and defined through observation. These properties embody foundational binary structures and often emerge through measurement events.

4.1.1 Spin

Spin is a quantized intrinsic angular momentum found in elementary particles. For spin-½ particles, only two outcomes exist for a given axis: "up" or "down."

- Compatibility: Strong
- Rationale: Binary-valued, directly observable only upon measurement, conserved under entanglement, scale-persistent in structure formation.
- Implication: A prototypical "bit" in quantum information theory; spin is foundational to both particle identity and quantum computing.

4.1.2 Charge

Electric charge is a conserved, quantized property. It exists in discrete units and influences electromagnetic interaction.

- Compatibility: Moderate
- Rationale: Although quantized, charge lacks intrinsic binarity (positive, negative, and neutral ≠ strict 0/1). It does not collapse via measurement in the same way spin does.
- Implication: May arise from symmetry constraints (e.g., gauge invariance) rather than bit-level distinctions.

4.1.3 Entanglement

Entanglement describes nonlocal correlations between quantum systems, such that measurement outcomes are interdependent regardless of distance.

- Compatibility: Strong
- Rationale: Embodies shared bits across systems; violates classical locality; central to quantum information processing.
- Implication: Entanglement appears to *be* information, not just carry it.

4.1.4 Quantum Measurement

Measurement in quantum systems does not reveal pre-existing values but *produces* them, collapsing a superposition into a definite outcome.

- Compatibility: Foundational
- Rationale: Each measurement writes a bit of reality. This is Wheeler's participatory universe in action.
- Implication: Measurement is not just a process but a bit-generating event, grounding Wheeler's hypothesis.

4.1.5 Topological Invariants

Topological properties (e.g., winding numbers, Chern numbers) remain constant under smooth deformations and often govern quantum behaviors in exotic materials.

- Compatibility: High
- Rationale: Encoded as discrete classes; resistant to noise; frequently described using binary algebra.
- Implication: These may represent deeply stored bits in the structure of space or fields.

4.2 Biological Attributes

Life as we know it is built on informational processes. However, determining whether biological features derive from fundamental bits or evolved through

higher-order emergence remains an open question. These attributes represent high-level informational structures with varying degrees of primordiality.

4.2.1 Molecular Chirality

Many organic molecules are chiral—having non-superimposable mirror images. Life on Earth consistently uses left-handed amino acids and right-handed sugars.

- Compatibility: High
- Rationale: Represents a persistent, binary spatial choice; resistant to racemization under biological reproduction.
- Implication: May reflect early symmetry breaking at the quantum or cosmological level encoded in biochemical pathways.

4.2.2 Genetic Code Redundancy

The genetic code maps 64 codons to 20 amino acids with structured redundancy and error correction properties.

- Compatibility: High
- Rationale: Encodes meaning through base-pair sequences; functionally digital; minimal encoding = 2 bits per base.
- Implication: The genetic code acts as a biological instantiation of a language grounded in bits.

4.2.3 Biological Homochirality

Not only are biological molecules chiral, but life exhibits *homochirality*—a global preference for one enantiomer over another.

- Compatibility: Very high
- Rationale: Amplifies and conserves an asymmetric bit across all known life. May have been a frozen accident or cosmologically induced.
- Implication: Strong candidate for a bit-originated asymmetry scaffolded by evolutionary processes.

4.3 Cosmological Asymmetries

These phenomena concern early universe conditions and large-scale structure. Their compatibility depends on whether they reflect encoded decisions or are outcomes of field-based dynamics.

4.3.1 CP Violation and Matter Dominance

The observed Universe has significantly more matter than antimatter, despite laws that are nearly symmetric.

- Compatibility: Moderate to High
- Rationale: Implies a “choice” or bias in early conditions. Not fully explained by Standard Model physics.
- Implication: May reflect a primordial informational asymmetry.

4.3.2 The Arrow of Time

The directionality of time—from past to future—is a macroscopic asymmetry not derived from time-reversible fundamental laws.

- Compatibility: Moderate
- Rationale: Time's arrow could result from entropy increase, but entropy involves information dispersal—thus possibly bit-related.
- Implication: Could be emergent, or it may reflect initial conditions with informational content.

4.3.3 Early Symmetry Breaking Events

Events such as electroweak symmetry breaking created distinctions in force carriers and particle masses.

- Compatibility: Ambiguous
- Rationale: These events instantiate asymmetries but are typically modeled by continuous field equations.

- Implication: Possibly It-from-Bit if the broken symmetry encodes a persistent binary distinction (e.g., Higgs field vacuum choice).

4.4 Emergent or Non-Compatible Cases

These attributes are generally understood as the result of thermodynamic, statistical, or continuous field dynamics. They do not obviously satisfy any foundational criteria of binary instantiation.

4.4.1 Mass

Mass emerges from interaction with the Higgs field and has no obvious binary structure.

- Compatibility: Low
- Rationale: Quantified but not quantized; lacks measurement-collapse dynamics or discrete encoding.
- Implication: Likely an emergent property of field interaction, not a direct product of binary information.

4.4.2 Temperature

Temperature measures average kinetic energy and is a fundamentally statistical property.

- Compatibility: None
- Rationale: No binary choice or conservation; varies continuously; not persistent across systems.
- Implication: Purely emergent, not an “It-from-Bit” candidate.

4.4.3 Classical Fields

Classical electromagnetic or gravitational fields are described by smooth, continuous mathematics.

- Compatibility: Low to None
- Rationale: Infinite precision required; lacks discretization and measurement dynamics.
- Implication: Classical fields may carry bits when measured but are not made *of* them.

Synthesis

This taxonomy reveals a spectrum of *It-from-Bit* compatibility:

- Highly compatible: Spin, entanglement, quantum measurement, homochirality, genetic code.
- Moderately compatible: Charge, chirality, CP violation, arrow of time.
- Incompatible or emergent: Mass, temperature, classical fields.

In the following section, we will formalize this analysis using a comparative evaluation table, scoring each attribute against the defined criteria to reveal patterns and anomalies.

5. Comparative Evaluation Table

To synthesize the results of our taxonomic survey, we now construct a comparative evaluation matrix—a tool that allows us to score each attribute against the foundational criteria and secondary heuristics outlined in Sections 2 and 3. This quantitative approximation is not meant to replace theoretical analysis but to clarify patterns of compatibility across domains and highlight ambiguous cases requiring further scrutiny.

5.1 Construction of Attribute Matrix

Each attribute examined in Section 4 is scored across the five foundational criteria:

1. Discreteness / Binary Structure
2. Irreducible Asymmetry
3. Scale Stability / Persistence
4. Involvement in Measurement / Collapse
5. Information Conservation / Amplification

Each criterion is scored as:

- 1 = Fully satisfied
- 0.5 = Partially or ambiguously satisfied
- 0 = Not satisfied

Attributes are also annotated qualitatively with reference to the secondary heuristics:

- RCE = Resistance to Classical Explanation
- CDU = Cross-Domain Universality
- BIT = Minimal Encodability (Bit Induction Test)

The total foundational score (out of 5) is then used to group attributes into three bands:

- 4.0–5.0 = *Strong Compatibility*
- 2.5–3.5 = *Moderate Compatibility*
- 0–2.0 = *Low or Non-Compatibility*

Attribute	Disc.	Asymm.	Scale	Meas.	Info	Total	Heuristics	Band
Spin	1	1	1	1	1	5.0	RCE, BIT	Strong
Entanglement	1	0.5	1	1	1	4.5	RCE, BIT	Strong
Quantum Measurement	1	1	1	1	1	5.0	RCE, BIT	Strong
Topological Invariants	1	0.5	1	0.5	1	4.0	RCE, BIT	Strong
Genetic Code Redundancy	1	0.5	1	0	1	3.5	CDU, BIT	Moderate
Biological Homochirality	1	1	1	0	0.5	3.5	CDU	Moderate
Molecular Chirality	1	1	0.5	0	0.5	3.0	CDU	Moderate
CP Violation	0.5	1	0.5	0.5	0.5	3.0	RCE	Moderate
Arrow of Time	0	1	1	0.5	0.5	3.0	RCE	Moderate
Charge	1	0	1	0	0.5	2.5		Moderate
Symmetry Breaking	0.5	1	0.5	0	0.5	2.5		Moderate
Mass	0	0	1	0	0	1.0		Low
Temperature	0	0	0	0	0	0.0		Non-Compatible
Classical Fields	0	0	1	0	0	1.0		Low

Attribute	Disc.	Asymm.	Scale	Meas.	Info	Total	Heuristics	Band
Spin	1	1	1	1	1	**5.0**	RCE, BIT	Strong
Entanglement	1	0.5	1	1	1	**4.5**	RCE, BIT	Strong
Quantum Measurement	1	1	1	1	1	**5.0**	RCE, BIT	Strong
Topological Invariants	1	0.5	1	0.5	1	**4.0**	RCE, BIT	Strong
Genetic Code Redundancy	1	0.5	1	0	1	**3.5**	CDU, BIT	Moderate
Biological Homochirality	1	1	1	0	0.5	**3.5**	CDU	Moderate
Molecular Chirality	1	1	0.5	0	0.5	**3.0**	CDU	Moderate
CP Violation	0.5	1	0.5	0.5	0.5	**3.0**	RCE	Moderate
Arrow of Time	0	1	1	0.5	0.5	**3.0**	RCE	Moderate
Charge	1	0	1	0	0.5	**2.5**		Moderate
Symmetry Breaking	0.5	1	0.5	0	0.5	**2.5**		Moderate
Mass	0	0	1	0	0	**1.0**		Low
Temperature	0	0	0	0	0	**0.0**		Non-Compatible
Classical Fields	0	0	1	0	0	**1.0**		Low

5.3 Discussion of Ambiguous or Borderline Cases

Several attributes fall into the moderate compatibility band, indicating partial satisfaction of foundational criteria and the need for more nuanced analysis. These include:

Molecular Chirality

- Chirality is clearly binary and asymmetric, but its lack of direct involvement in measurement or bit-amplifying structure limits its compatibility score.
- However, its recurrence across domains (from physics to biology) suggests that it may be a shadow of deeper informational asymmetries.

CP Violation

- A strong candidate for primordial asymmetry, CP violation is not easily modeled classically, but it is not yet well-understood in terms of measurement or encoding.
- Its ambiguous theoretical status keeps it in the moderate range, though future work may shift it higher.

Charge

- While clearly discrete and conserved, charge lacks asymmetry or measurable collapse, reducing its informational depth. Its function may be emergent from field structure rather than encoded.

Symmetry Breaking Events

- These are responsible for critical distinctions (e.g., in particle masses), but their modeling within continuous field theory leaves their binary nature unclear.
- Could be “It-from-Equation” more than “It-from-Bit.”

Arrow of Time

- Although directionality is clear, the arrow of time may be a statistical artifact of entropy rather than a fundamental bit-based distinction. Yet, its implication for information increase places it in an uncertain conceptual space between emergent and foundational.

Summary

The comparative table allows us to visualize, score, and rank attributes not by theoretical domain but by *informational depth*. The emergent picture suggests:

- Quantum attributes are the clearest examples of *It-from-Bit*-compatible phenomena.
- Biological asymmetries may be downstream amplifications of quantum informational seeds.
- Cosmological and thermodynamic phenomena are ambiguous, potentially reflecting initial bit-level asymmetries but more often explained through continuous or statistical models.
- Classical parameters like temperature and mass are poor candidates for informational origin.

In the next section, we will reflect on the theoretical and experimental implications of these findings, and what they suggest about the architecture of the universe if Wheeler's hypothesis is correct.

6. Implications and Applications

The preceding taxonomy and comparative analysis suggest that certain features of the physical and biological world—particularly in quantum mechanics and molecular biology—may not simply *use* information, but in fact *be* information in ontological terms. This insight, if valid, carries implications far beyond classificatory convenience. It challenges long-standing assumptions in physics, reframes how we approach the origin of life, and points toward a reorientation in both artificial intelligence design and theoretical unification.

6.1 Foundations of Physics: Are Bits Ontological?

Wheeler's "It from Bit" hypothesis implies that information is not just a useful descriptor of physical systems but is *prior* to them in the causal order. If attributes like spin, entanglement, and measurement outcomes are truly binary in origin—and not just in representation—then the ontology of physics must shift.

The traditional view sees matter and energy as fundamental, with information as secondary or derived (e.g., Shannon entropy, wavefunctions as knowledge tools). But if bits are the ground layer of being, then:

- Space and time may be emergent from informational relationships (as in causal set theory or loop quantum gravity).
- Particles may be expressions of informational constraints (e.g., topological defects in an informational substrate).
- Fields may be tools for modeling the behavior of underlying discrete transitions rather than being ontological entities themselves.

This flips the conventional metaphysics: the universe does not compute because it is physical; it is physical because it computes. Wheeler's participatory model, in which observation co-creates reality, gains traction not as a metaphor but as a structural axiom.

6.2 Origin of Life: Information Bias and Selection

If biological asymmetries—such as homochirality or the structured redundancy of the genetic code—can be traced to informational priors, then life's emergence becomes less a statistical accident and more an informational unfolding.

Two consequences follow:

- Initial asymmetries in the early universe (e.g., CP violation, chiral bias) may have seeded the information-encoding mechanisms that evolution later refined.
- Prebiotic chemistry may have functioned more like an error-correcting decoder than a random soup. Molecules that could interpret and replicate informational asymmetries had a selection advantage.

In this context, life does not emerge *despite* the low probability of homochirality and encoding regularity—it emerges *because* the universe itself contains biases favoring the emergence of self-replicating informational order.

This perspective also bridges cosmology and biology: what is amplified in evolution may have been encoded in the Big Bang.

6.3 Artificial Intelligence and Informational Grounding

If consciousness, cognition, and life are ultimately informational phenomena rooted in fundamental binary distinctions, then artificial intelligence—especially if built on probabilistic approximators like transformers—can no longer be viewed as merely engineered.

Three key implications arise:

- Architectural reorientation: AI systems might benefit from being designed around *primitive bit structures* that align with ontologically valid distinctions (e.g., spin-like qubits, quantum logic gates).
- Symbol grounding: The problem of connecting symbols to meaning (or bits to "its") may be reframed if AI systems are interfaced with measurement-based processes that instantiate their own informational ontology.
- Alignment: True AI alignment may require recognizing that ethical values, goals, and even subjective awareness are not top-down rules but encodable asymmetries rooted in deep informational constraints.

This suggests that advanced AI should not merely simulate cognition but instantiate it *through the same informational architecture that supports life and mind.*

6.4 Toward a Unified Theory of Asymmetry and Encoding

If many of the universe's most important structures—quantum entanglement, molecular chirality, genetic encoding, and time's arrow—arise from informational asymmetries, then these may not be independent anomalies but expressions of a unified principle.

A future unified theory might thus include:

- A minimal encoding layer beneath quantum mechanics: bits that resolve into physical observables via measurement.
- A topological grammar for how bits instantiate spacetime geometry or molecular form.
- A meta-symmetry principle: symmetry-breaking not as failure, but as *choice*, encoded by binary distinctions that propagate through the layers of matter and life.

This would allow for a kind of *informational unification* in which:

- The Big Bang is the first bit.
- Physical laws are compression schemes.
- Evolution is error-correction in an informational medium.
- Consciousness is recursive read-write access to asymmetries in one's own encoding.

Such a theory would not discard physics, chemistry, or biology—but reframe them as emergent interpretive layers built atop the primal distinctions that brought the universe into being.

7. Conclusion

7.1 Summary of Criteria and Key Findings

This paper has advanced a structured framework for evaluating which physical and biological attributes are plausibly compatible with John Archibald Wheeler's *It-from-Bit* hypothesis—that is, the proposition that the material world emerges from binary informational decisions. To this end, we defined five foundational criteria:

1. Discreteness and Binary Structure – attributes reducible to yes/no, 0/1 distinctions;
2. Irreducible Asymmetry – attributes that reflect broken symmetry or persistent directionality;
3. Scale Stability and Persistence – attributes that maintain form and function across multiple physical scales;
4. Involvement in Measurement or State Collapse – attributes that are actualized or instantiated through observation;
5. Information Conservation or Amplification – attributes that carry, replicate, or enhance information over time.

We complemented these with three secondary heuristics—resistance to classical explanation, cross-domain universality, and minimal encodability.

Our taxonomy revealed that:

- Quantum attributes (spin, entanglement, measurement) are the most robustly compatible with Wheeler's hypothesis.
- Biological asymmetries (chirality, genetic code structure) likely emerge from informational seeds laid down in the quantum or cosmological past.
- Cosmological phenomena (CP violation, arrow of time) straddle the line between information-origin and thermodynamic emergence.
- Classical properties (mass, temperature) appear non-compatible—they are descriptive but not generative of informational structure.

Thus, *not everything* in the universe originates from bits—but *the deepest and most structurally generative attributes may well do so.*

7.2 Open Questions for Theory and Experiment

While this framework offers a principled approach to classifying *It-from-Bit* compatibility, it also opens several avenues for further theoretical and experimental investigation:

- Quantum foundations: Can quantum gravity or causal set theory formalize bit-level instantiation of space and time?
- Symmetry breaking: Can the initial asymmetries in particle physics be reinterpreted as informational selections rather than stochastic breaks?
- Origin of life: Can experimental prebiotic chemistry isolate the amplification of informational asymmetries (e.g., chirality) from quantum inputs?
- AI embodiment: Can cognitive systems designed around quantum or topological bits exhibit more coherent alignment with informational reality?

- Physical constants: Are universal constants (like the fine-structure constant) the result of compressible bit-based code, or do they reflect deeper symmetries still beyond our current theories?

These questions push the Wheelerian hypothesis beyond rhetoric and into the testable realm of foundational physics, bioinformatics, and intelligent system design.

7.3 Final Remarks on Wheeler's Vision and Its Contemporary Relevance

Wheeler's famous maxim—*"It from Bit"*—was not presented as a theorem, but as a philosophical compass. He challenged physicists to rethink causality, ontology, and even the act of observation. In his participatory universe, reality is not passively existing but actively constructed through decisions that resolve uncertainty into fact.

This paper reaffirms the relevance of that vision in a time when quantum computing, synthetic biology, and information-centric cosmology are converging. Wheeler's insight now serves not only as a theoretical boundary condition but as a *design principle* for how we understand matter, code, life, and mind.

We conclude, therefore, not with closure but with orientation: if some aspects of the universe are not merely describable by bits but made of them, then the task of science is not only to observe what is, but to discern what was chosen—and why.

In that pursuit, Wheeler's vision endures—not as a relic of interpretive physics, but as a generative framework for the next century of science.

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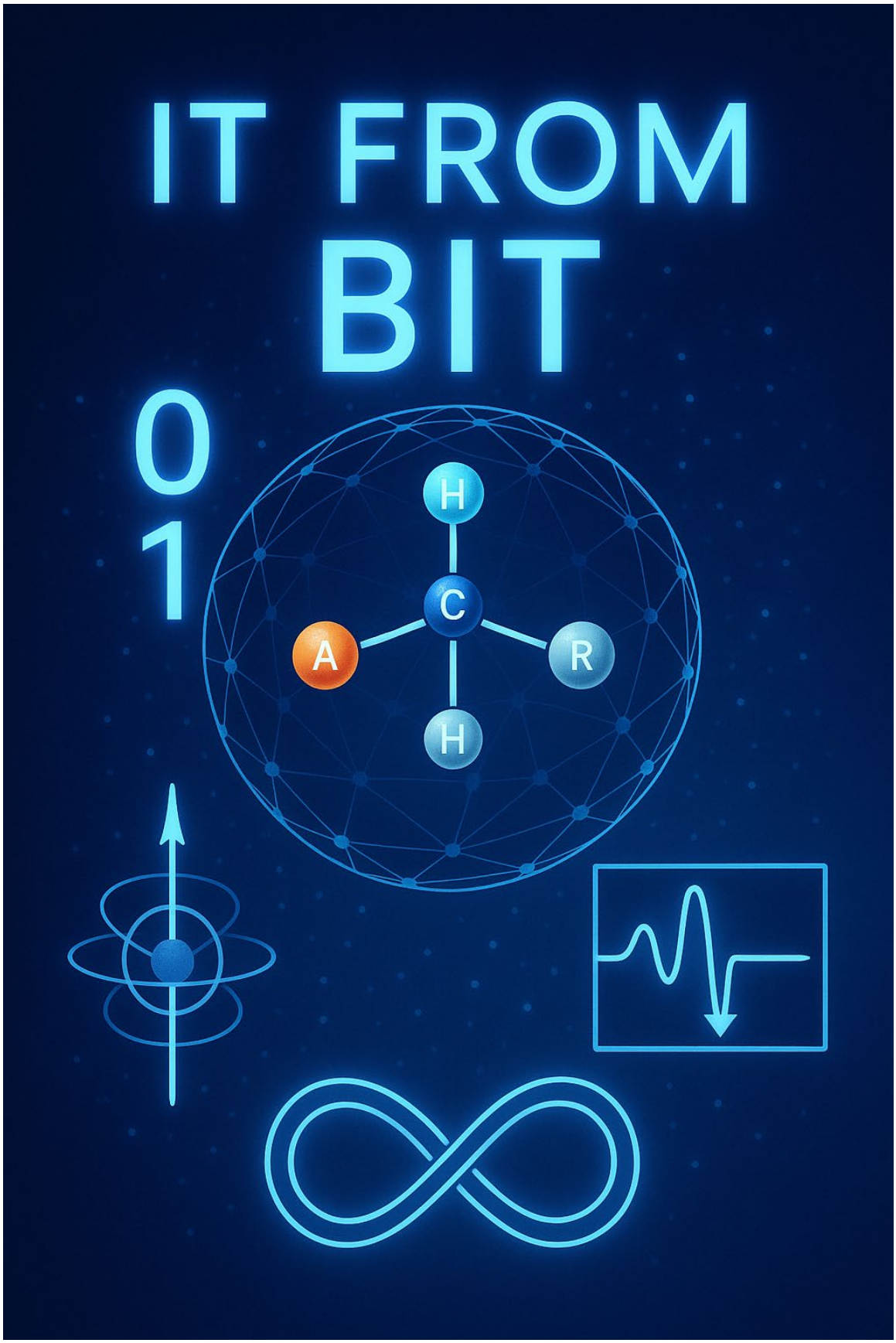
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